SAFETY ASPECTS OF CONTROLS AND OPERATIONS OF BELT CONVEYORS IN COAL MINES

BY C. L. BROWN

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C. L. Brown[1/]

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INTRODUCTION

Coal has been transported by belt conveyors in mines for many years; however, only since the beginning of the general mechanization period have complete transportation systems of this type been employed. Aside from many complete belt-conveyor transportation systems, belt conveyors are frequently used in conjunction with other transportation. Many early installations, for the most part, were made without standards as a guide. As a result, some States have outlined certain requirements based more or less on experience following mine fires. Correlation of these regulations should result in more uniformity in connection with standardization of regulations. The National Electrical Manufacturers Association has published standards for mining-belt-conveyor installations[2] that should be helpful to the coal-mining industry generally.

Bureau of Mines Schedule 2F[3] requires certain controls for permissible-belt-conveyor drives, and similar requirements are listed in Bureau of Mines bulletin 514.[4] Committees of the American Mining Congress have prepared much valuable information concerning operation of belt conveyors, and a subcommittee on fire-resistant belting has been active.[5]

Belt conveyors were involved in a large number of fires in coal mines in the United States from 1947 to 1955. Investigation of these fires revealed that most of them could have been prevented by minor precautionary measures. The frequency of mine fires has focused attention on the necessity of utilizing all available knowledge to prevent them. In recognition of these hazards, certain requirements regarding installing and operating belt conveyors were included in the 1953 Federal Mine Safety Code. The requirements of article X, section 1L, of this code are as follows:

> Underground belt conveyors installed after the effective date of this Code, unless fire-resistant, shall be equipped with control switches to automatically stop the driving motor in the event that the belt is stopped by slipping on the driving pulley, by breakage, or other accident.

2/ National Electrical Manufacturers Association, Standards for Mining Belt Conveyors: Pub. MB1 - 1954, January 1954.

3/ Bureau of Mines, Electric Motor-Driven Mine Equipment, Junction Boxes, and Other Accessory Equipment: Sched. 2F.

4/ American Standards Association, American Standard Safety Code for Installing and Using Electrical Equipment in and About Coal Mines (M2.1) (Sponsored by Bureau of Mines and American Mining Congress): Bureau of Mines Bull. 514, 1952, p. 24.

5/ Reports of American Mining Congress Conveyor Committee have been published in the Mining Congress Journal.

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Additional control equipment for efficient and safe operation of belt conveyors is also discussed briefly in this paper.

ACKNOWLEDGMENTS

The assistance of belt-conveyor and equipment manufacturers in providing photographs used herein and the assistance of Bureau personnel and others in preparing this material are gratefully acknowledged.

BELT-CONVEYOR INSTALLATIONS, EQUIPMENT, AND CONTROLS

Belt-Conveyor Applications

In addition to using belt conveyors to transport coal, they are sometimes used to transport refuse, supplies, or men. Where belt conveyors have multiple uses, controls are available to accomplish the desired functions. Common application of belt conveyors for transportation of materials underground includes:

1. Transportation to surface on slope.
2. Main underground transportation (mother conveyors).
3. Secondary or feeder conveyors.
4. Room conveyors (including extensible belts).
5. Face conveyors.

Belt-conveyor applications vary from the simple slope installation to complete systems of conveyor transportation. Other means of transportation are frequently used in combination with belt conveyors; for example, main transportation may be by track equipment with belt conveyors as intermediate transportation between the track system and working sections. The use of shuttle cars in combination with belt conveyors is widespread also.

Where men are transported by belts in coal mines, they are frequently transported in an outward direction only; however, provision is sometimes made for a reversing mechanism that permits transportation in both directions. Among the several requirements of the Federal Mine Safety Code for transporting men on belt conveyors is the limitation of belt speed to 250 feet per minute. Therefore, where men are to be transported and the normal operating speed of a conveyor exceeds 250 feet per minute, 2-speed controls are required in order to meet the provisions of this code.

Belt-Conveyor Drives

The type of drives used for belt conveyors varies widely. The selection of drive is usually determined by a number of factors, including the initial cost. Generally the gear-reduction unit, totally enclosed in a substantial housing and running in a bath of oil, coupled directly to the belt-conveyor-drive pulley, is the ideal drive. It is highly efficient, requires minimum maintenance, and presents minimum hazards to workmen. Other drives may consist of gear motors or chains and countershafts. Tandem drives are generally selected where high belt tension and large power input are required. These factors are, of course, determined by length of belt, loading, and gradient. The tandem drive is usually selected for coal mines because of the wide variation in operating conditions encountered.

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Motors for Belt-Conveyor Drives

The starting torque requirement of a conveyor is an important factor in selecting the drive motor. The general-purpose squirrel-cage motor will fulfill the requirements of most alternating-current installations; however, some conveyors require torque for starting that exceeds the output of this motor. Such requirements necessitate the use of high-torque, squirrel-cage, or wound-rotor induction motors. Although alternating-current drive motors offer certain advantages over direct-current motors on some applications, the direct-current drive is frequently used in coal mines for reasons of variable speed requirements and availability of the power supply. Speed regulation of belt conveyors in series, using direct-current power, may present a problem where the power supply is inadequate; however, satisfactory regulation can be obtained where deficiencies in the power supply are corrected.

Open-type motors are objectionable for use in hazardous locations. Motors installed at locations where explosive quantities of dust or gas may be present require special enclosures.

Control Equipment for Belt Conveyors

The selection and application of proper control equipment for belt-conveyor installations are considered of primary importance from the standpoint of safe and efficient operation. The services of a competent consultant are usually justified on important installations.

Motor-starting controls are selected on the basis of the type and size of motor used, the torque required to accelerate the conveyor, whether or not the conveyor is to be reversed, and the number of operating speeds.

In addition to the main starting controls, certain auxiliary controls are required for safe, efficient operation. The requirements for auxiliary controls will vary, depending on the particular conveyor installation and operating practices. Auxiliary controls have not been standardized, and the development and application of such controls in the mining industry have resulted from the needs and requirements of various installations. Many auxiliary controls have been made by mechanics and electricians in the mining industry to fill the requirements of their particular needs. Important auxiliary controls for conveyors are:

1. Emergency stop.
2. Sequence start and stop.
3. Test run provision.
4. Protection against overflow of material.
5. Protection against accidental reversal and overspeeding.
6. Protection against roof falls.
7. Protection against misalinement.
8. Protection against excessive belt slippage.

An elementary wiring diagram of a belt-conveyor-motor control, including some auxiliary devices, is shown in figure 1.

Emergency stop controls located to permit quick stoppage from strategic points are considered necessary to provide safety for persons and equipment. This feature consists of one or more start-stop pushbuttons, switches actuated by pull cords, or other means for stopping the drive motor from remote locations. Ratchet-type

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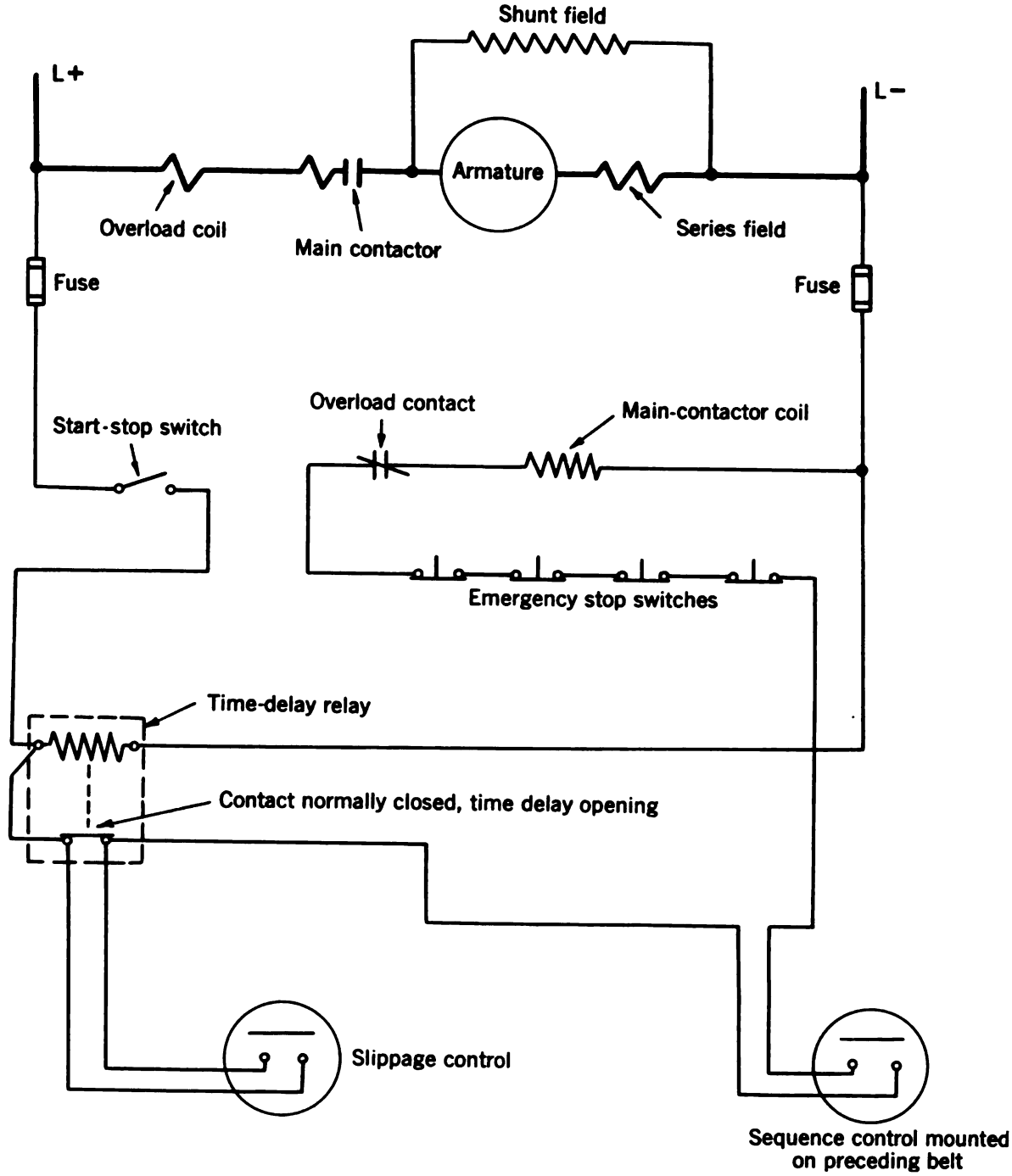

Figure 1. - Elementary wiring diagram for belt-conveyor motor circuit, showing emergency stop, sequence, and slippage controls.

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switches or switches designed in a manner to require two successive operations of the mechanism to restart are preferred for most installations.

Where a single conveyor unit is operated independently of any other conveyor, any starting controller incorporating the necessary electrical protective features and arranged to properly accelerate the conveyor will suffice. However, the problem is rarely that simple, because a conveyor system may consist of several units, in which case it is desirable to have the controls for all units interlocked in such a way that the units will start in proper sequence. This feature is considered necessary to reduce overloading and power demand and to prevent spillage at transfer points. Conveyors can be controlled in sequence by using control circuits between driving units or by using devices actuated by movement of the belts. The latter method is generally preferred, because long control circuits are eliminated and more positive protection is provided. Control devices may be actuated by an outby belt to provide sequence control for the next inby belt. This requires a mechanical connection to the outby conveyor for the sequence control and an electrical connection to the starter of the next inby conveyor. The devices are usually driven by rollers in contact with the outby belt; however, they may be driven by other means. Devices available for sequence control include:

1. Centrifugal switches.
2. Magneto or generator.
3. (Magnetic) eddy current switches.

Figures 2, 3, 4, 5, 6, and 7 show devices suitable for sequence and slippage control. Where sequence control is employed, the outby conveyor must be started first. After the first conveyor has reached the predetermined speed setting, the next inby conveyor is started automatically in sequence. A slowdown or stop of any conveyor in the system will stop all inby conveyors.

In case of tests and adjustment, it is frequently necessary to operate conveyors in a system separately. Where sequence control is used, it is necessary to provide a means for bypassing this control while testing each individual conveyor. A normally open contact pushbutton is preferred for such applications to insure that the sequence control circuit will be restored to normal after tests have been completed.

Modern direct-current starters for reversing require an extra contact on the reverse drum so that the next inby conveyor will not start while its outby conveyor is running in a reverse direction. Alternating-current reversing starters are generally equipped with a forward-reverse-stop momentary contact pushbutton control circuit that is not readily adaptable to sequence operation; however, other alternating-current starters do not present special problems.

Protection against chute clogging and piling up of material at discharge points is considered important on most belt-conveyor systems. This protection is usually provided by a simple arm or vane connected mechanically in a manner to actuate a switch in the control circuit that will stop the motor if the material piles up. Numerous schemes have been used to control the flow of material being discharged from one conveyor to another to prevent overloading. Some of these devices are actuated by the flow of material, and one is actuated by the variation in sag of the belt caused by the change in amount of material on the belt.

Protection against accidental reversal of inclined belt conveyors is necessary on installations where failure of power or mechanical parts may cause serious

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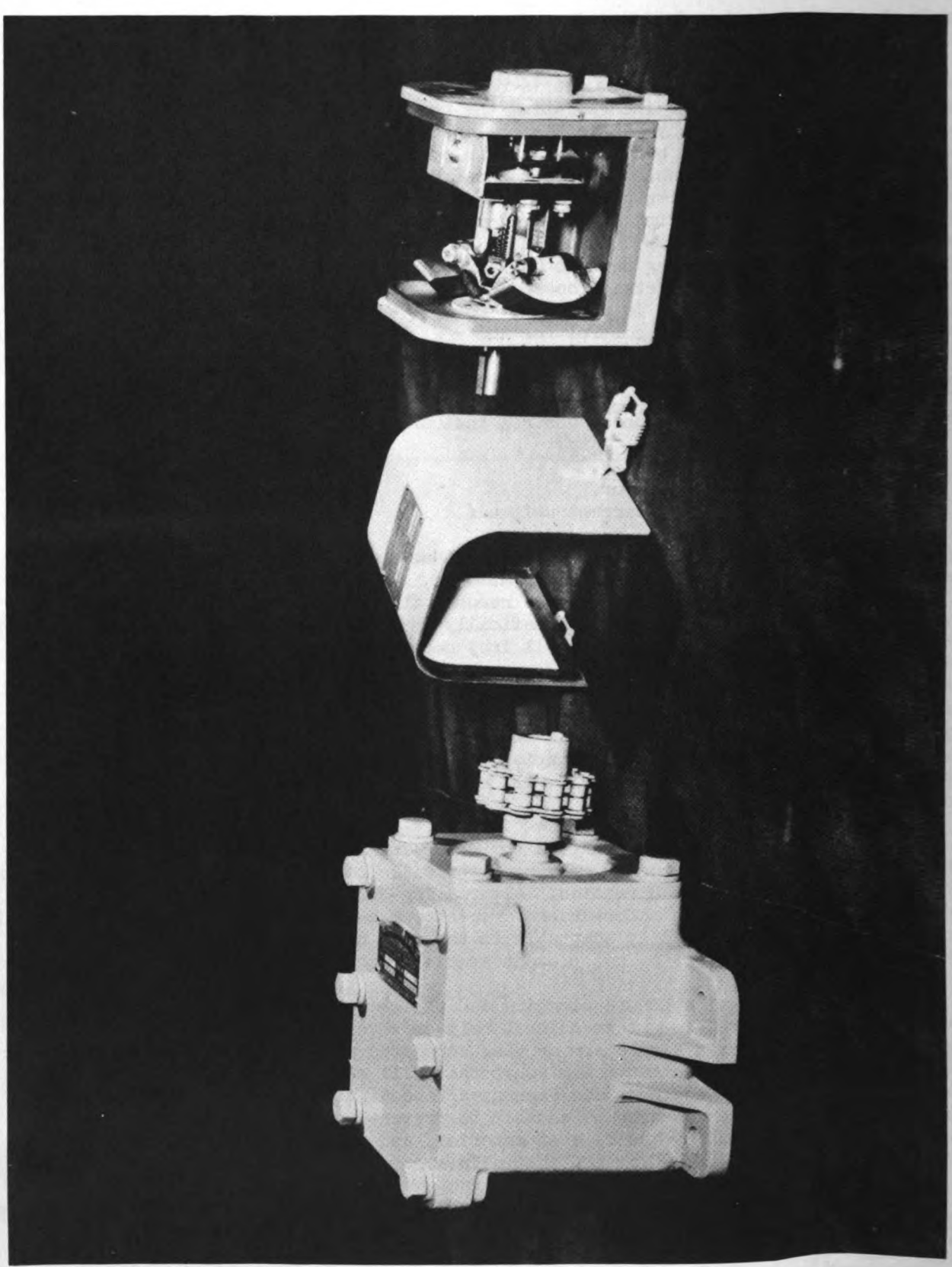

Figure 2. - Explosion proof (left) and open-type (cover off) centrifugal switches for belt slippage or sequence control.

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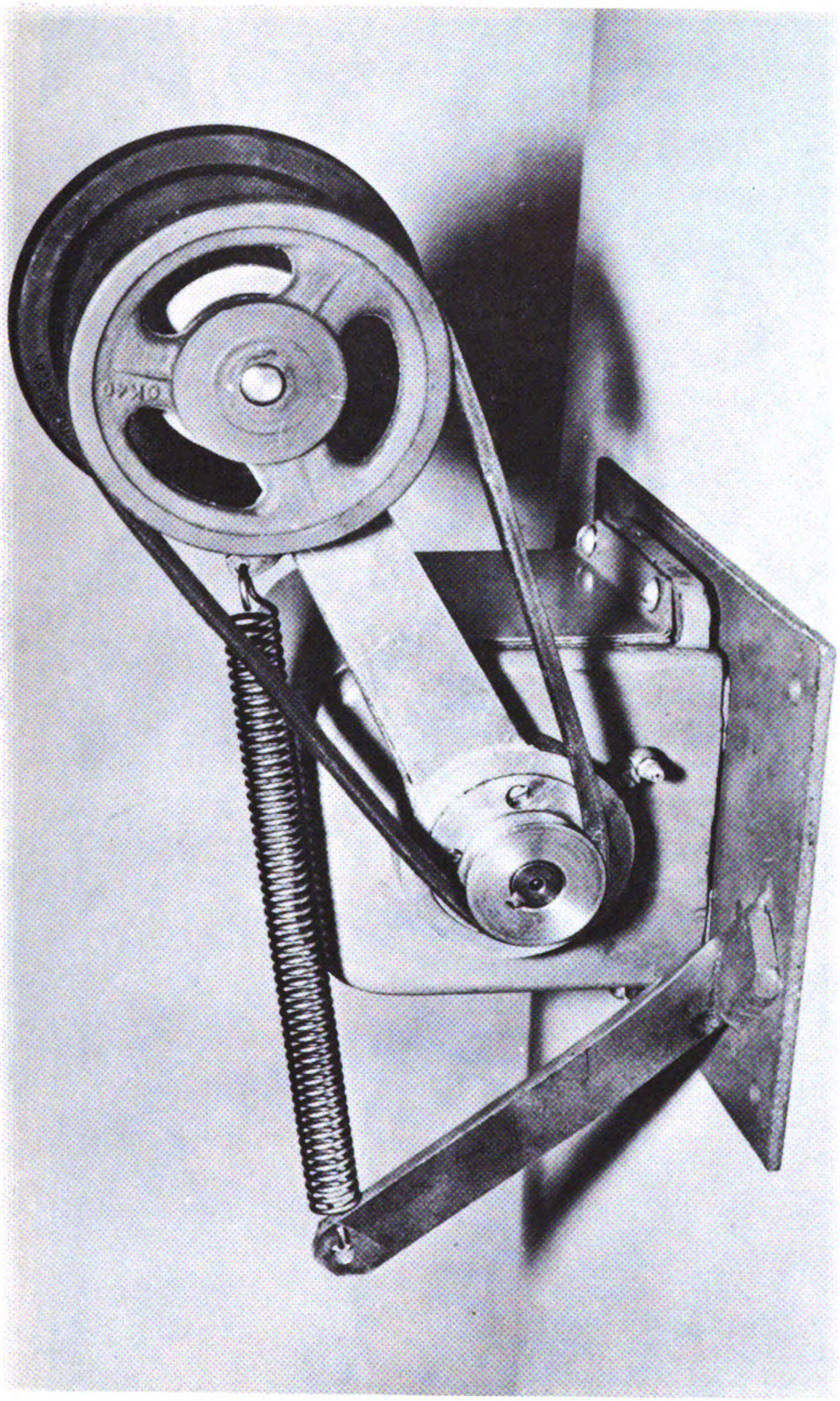

Figure 3. - Centrifugal switch with contact pulley for mounting under carrying side of conveyor belt.

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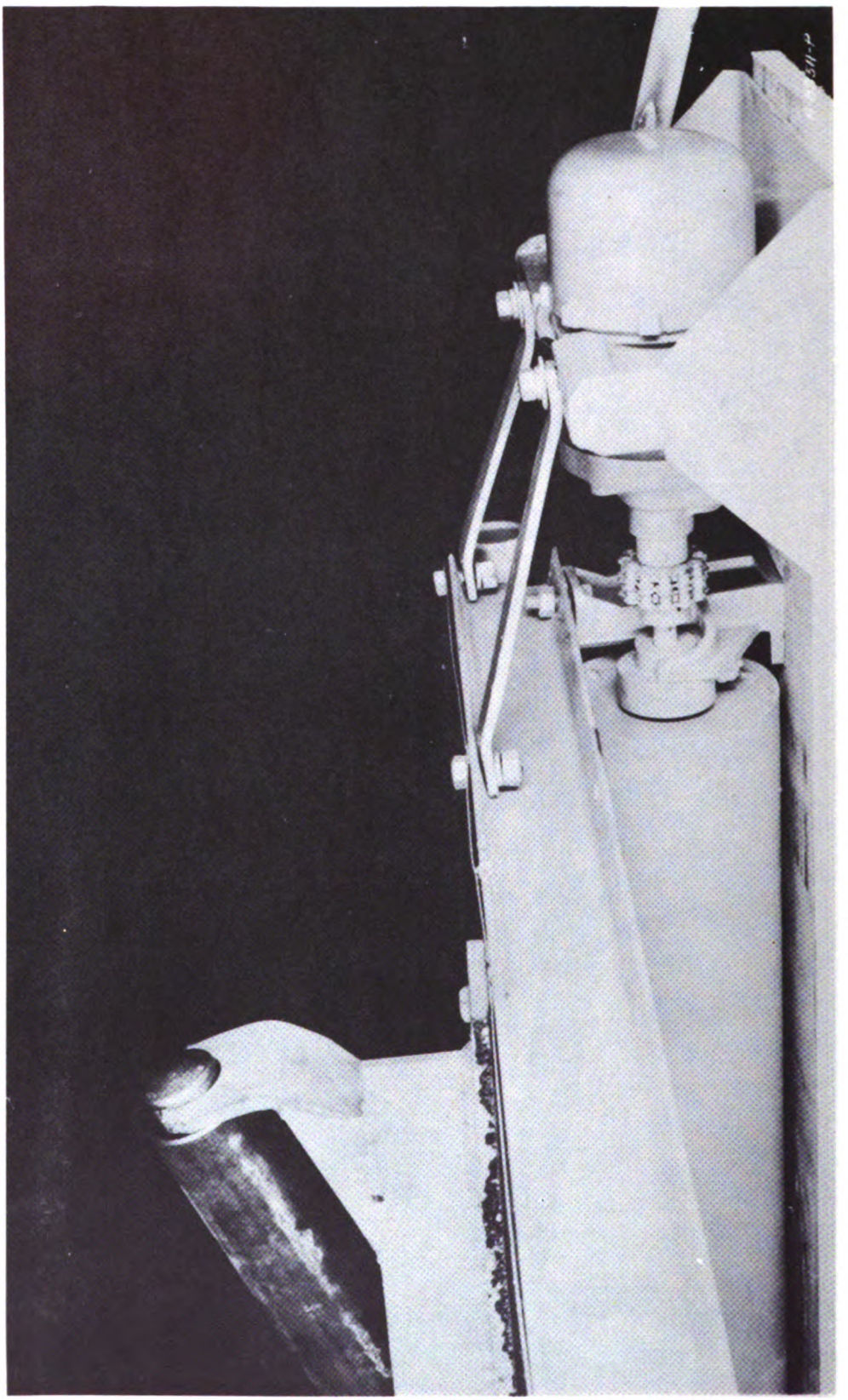

Figure 4. - Magneto driven by return idler.

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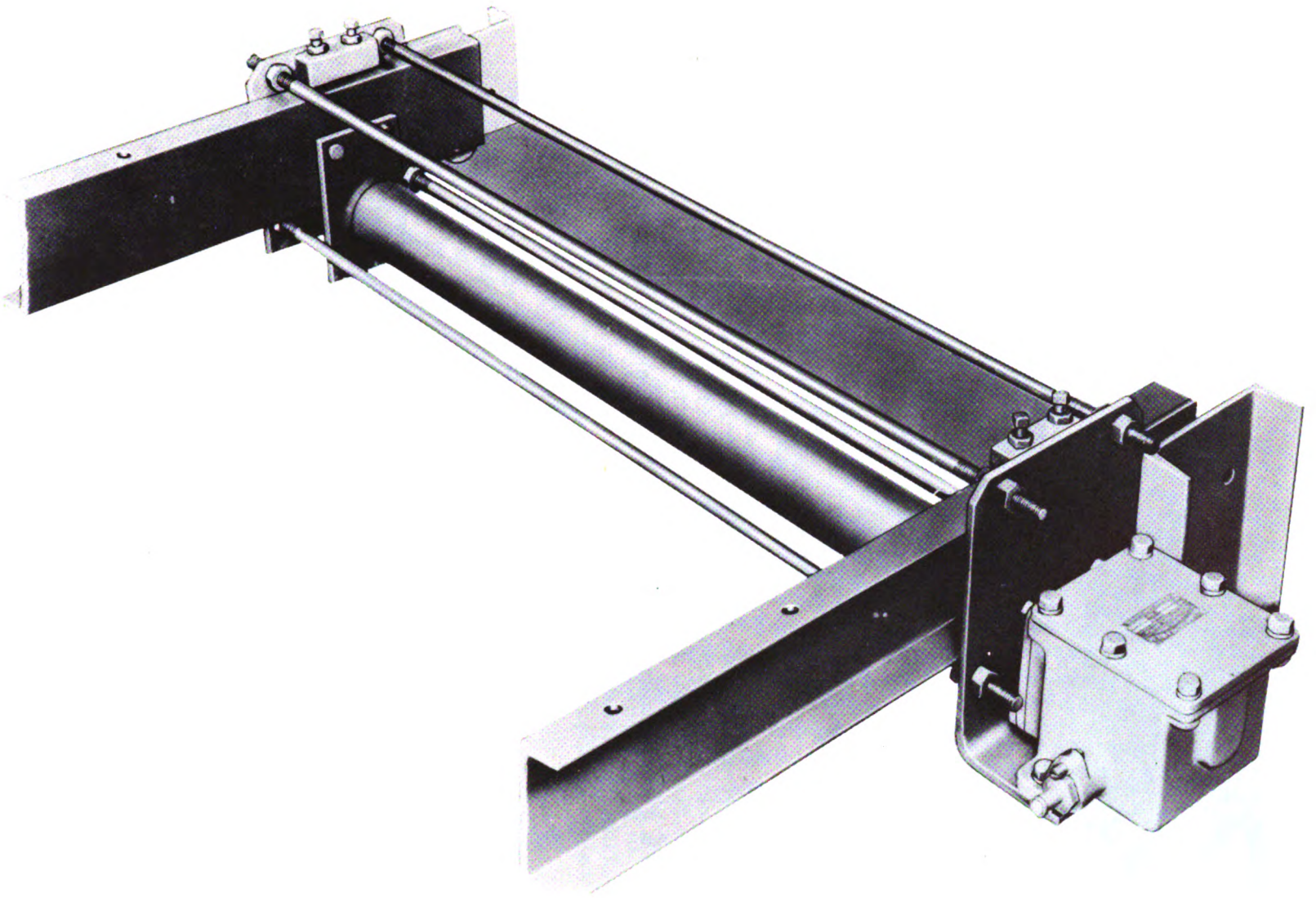

Figure 5. - Centrifugal switch mounted on belt-conveyor frame and driven by idler roller.

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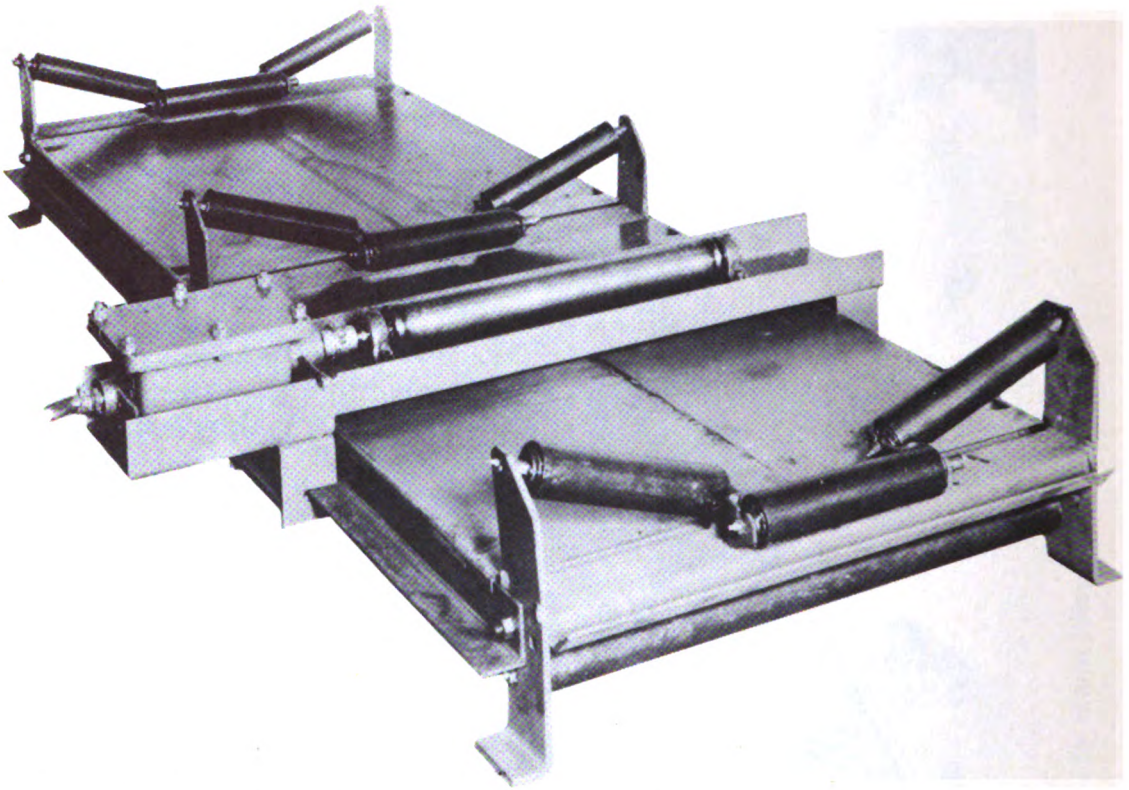

Figure 6. - Centrifugal switch driven by roller, mounted under carrying side of belt.

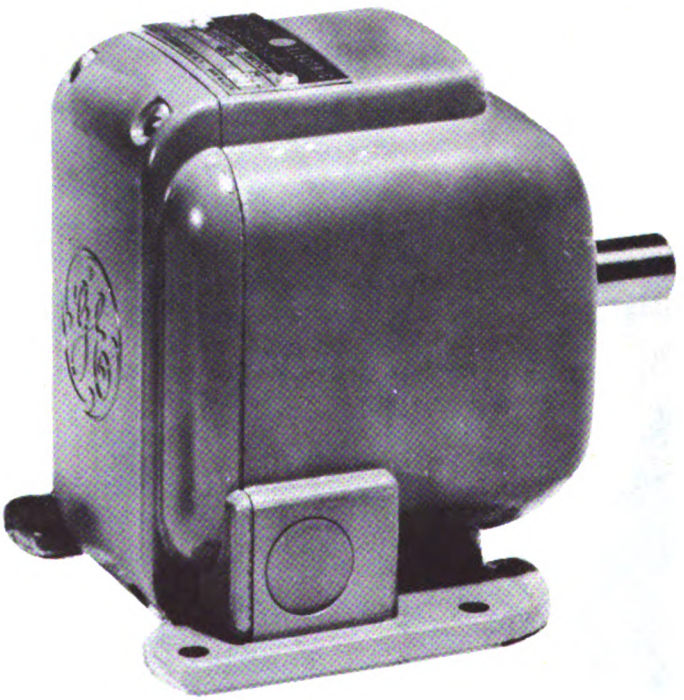

Figure 7. - Plugging switch adaptable to slippage and sequence control.

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overspeeding. Devices used for this purpose are generally known as holdbacks. The three principal types are:

1. Roller holdback.
2. Ratchet holdback.
3. Differential band brake.

The roller holdback, although more expensive, is considered more reliable than some other types. The selection of a holdback is generally determined by the importance of the protection required. Declined belt conveyors are rarely used in coal mines; however, where they are used the holdback cannot be applied. A brake, disengaged electrically, is commonly used to prevent runaways on such installations. Dynamic braking is also frequently used on declined conveyors for speed control.

Falls of roof in coal mines are recognized as a hazard in the operation of belt conveyors. In addition to providing adequate roof support over conveyors, much consideration has been given to automatic protection against accidental stoppage of belts by falls of roof. One method employed is the use of a control circuit constructed with easily separated connectors spaced at frequent intervals and installed above and throughout the length of the conveyor, the function being to stop the drive motor when falling roof material that might be harmful causes separation of the connectors in the control circuit.

Much emphasis is now being placed on automatic devices to maintain proper alinement of the belts on both carrying and return sides to prevent damage from edge wear on the belt and possible ignition of combustible materials by friction. These are usually automatic mechanical devices that train the belt when it runs to either side. Training idlers are available that will perform this function for the carrying and return sides of belts. Controls can be provided that will stop the drive motor when the belt runs out of alinement a predetermined amount. Under certain conditions these controls may be considered necessary to protect the equipment against serious damage.

The purpose of the requirement in the Federal Mine Safety Code for protective devices on belt conveyors is to prevent belt fires and self-destruction of the belt. Mine fires may occur if the belting of a conveyor breaks, fouls, or loses tension in such a manner that the driving pulley continues to rotate with the belt slowed down excessively or stopped. It is believed that within the speed ranges of belt-conveyor operation the belt slip should not exceed about 25 percent of the normal speed. Slippage above this amount may generate enough heat to ignite combustible materials, including belting of natural rubber. It is now considered good practice to provide protection against excessive belt slippage regardless of whether the conveyor belt is of flame-resistant material, operated automatically, or attended. Belts may be protected against slippage by a safety device applied to any belt conveyor that has a magnetic starter or other device with a no-voltage release to control the driving motor.

The same-type devices as those used for sequence control when applied differently may be used for slippage control. In general, belt-slip protection involves a suitable device to be actuated by belt movement and connected into the starting-control circuit of the driving motor. Since the device renders the motor starter inoperative between zero and a predetermined operating belt speed, a means must be provided for bypassing the device during the starting cycle. It is important that equipment be selected that will provide protection against excessive slip on starting as well as while running. For example, a fully loaded belt is most likely to slip excessively when an attempt is made to start it, and a belt that is fouled may

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result in 100-percent slip. This operation is done most satisfactorily by an automatic auxiliary relay that may be external to or built into the motor starter.

The method of driving devices for slippage control is similar for all types with slight variation in details as supplied by different manufacturers. Most devices in use in this country depend on contact with the belt as a means of driving the mechanism, although other means of driving may be employed. The contact mechanism may be a substitute or idler roller or a contact roller on a movable arm. Common devices available for belt-slip protection may be classified into three general types as to operating mechanism. These are: (a) Centrifugal switch, (b) (magnetic) eddy current switch, (c) magneto or generator. The centrifugal switch has been used most widely up to this time. Unfortunately most belt-slip controls are not readily adjustable throughout the speed range of all belt conveyors. Each type usually has adjustment within a certain speed range, but most require internal changes in order to be applicable to all belt speeds. The matter of proper adjustment and maintenance of belt-slip controls is most important in order that effective protection may be assured. Some authorities believe that slippage of rubber belts should not exceed about 25 percent of normal speed for the average belt. However, the amount of slip that can be permitted with safety will vary with such factors as width and length of belt, speed, and loading. To insure safety, adjustments for operating speed must be made in accordance with these factors and settings made to limit belt slippage to less than 25 percent of normal speed.

Figure 1 shows an elementary wiring diagram of a belt conveyor drive motor with slippage and sequence control for inby units in a series. All units in a series would be wired in a similar manner except the first outby unit, which would have a start-stop button wired in a manner to prevent restarting automatically after stopping for any reason and the sequence control switch is omitted.

The devices for belt-slip protection may be distinguished from those for sequence starting by their location on the belt. For example, sequence-control switches are installed near the inby end of belts, whereas switches for slippage control are installed near the drive end. Installations are made at these locations to keep the length of the control circuits at a minimum. A typical installation of belt conveyors is shown in figure 8.

Research and Development of Other Methods and Devices for Preventing Belt Fires

Providing fire-fighting equipment to combat fires developing in belt-conveyor systems does not always eliminate risk, and the failure of apparatus at the critical moment can have, and has had, disastrous results. Recognition of this fact has prompted experimentation with thermal devices, as well as the various devices that are intended to function from a predetermined amount of belt slip. One manufacturer is experimenting with a thermal-actuated control that is intended to pick up radiated heat from the belt-drive pulley. Heat radiated in this manner is utilized to prevent a temperature rise above a predetermined value on the drive pulley by stopping the drive motor. This principle has not been utilized in devices for belt protection in this country.

Some experimentation has been done by the Bureau and others with thermal-actuated stench-warning capsules mounted on belt-drive pulleys; however, no installations have been made in coal mines up to the present time.

Since the coal-mining industry in foreign countries has hazards similar to those in this country, the seriousness of belt fires has resulted in considerable experimentation to develop devices for protecting belt installations. One system

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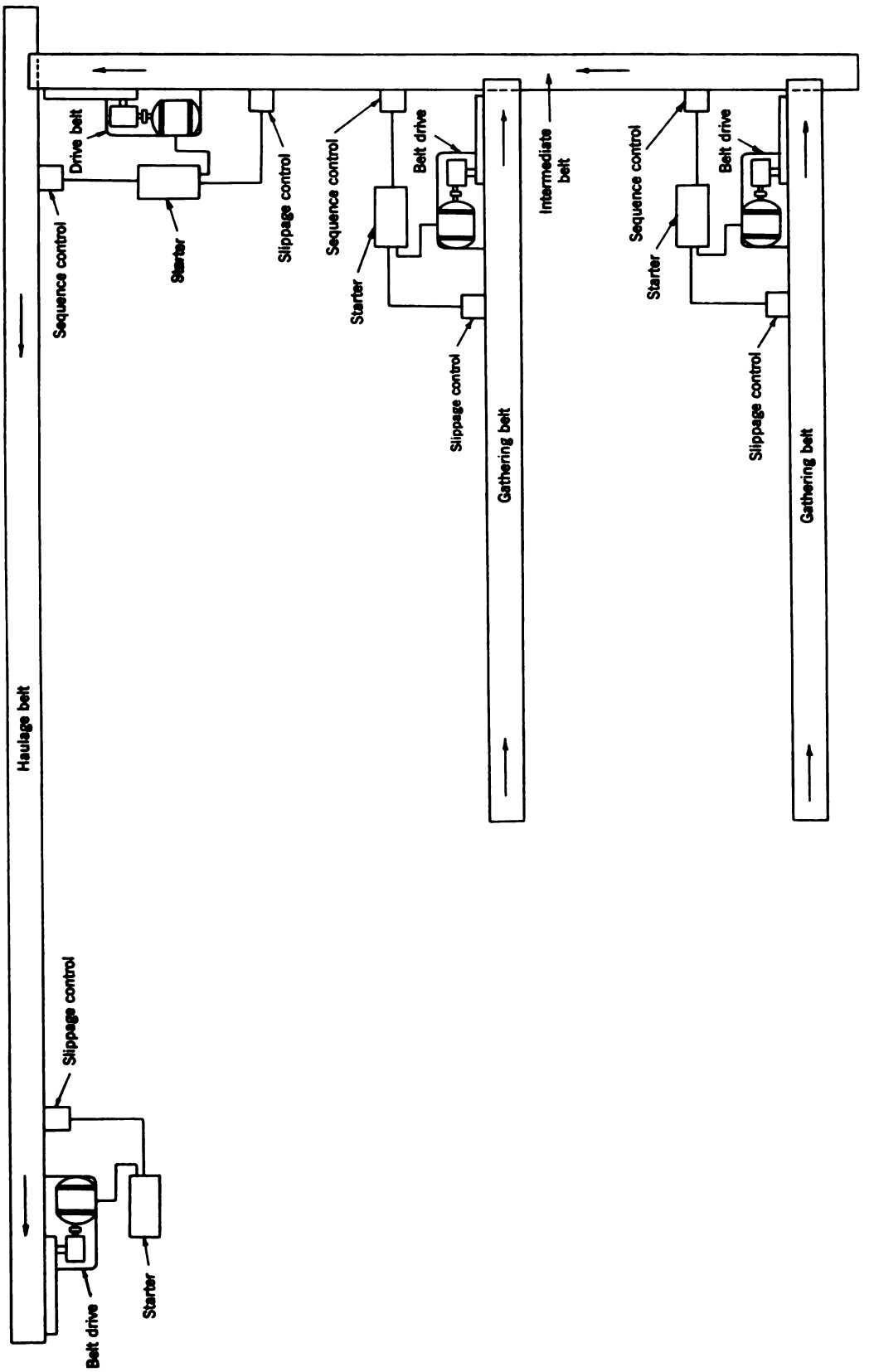

Figure 8. - Typical installation of belts showing application of sequence and slippage controls.

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comprises a low-voltage, balanced electrical circuit with no contacts or moving parts in the external detecting elements. This unit is designed to assess the amount of heat being dissipated from the driving head and to compare it with the normal air temperature at the drive location. Thus, overheating a belt-drive unit is expected to cause an increase in the electrical resistance of the detecting element. The resulting unbalance in the circuit is utilized to actuate relays controlling the drive motor. The system is designed to have multiple detecting elements installed in the airway.

Another scheme is a thermal-actuated device built into the drive pulley and connected by mechanical linkage to contacts in the control circuit of the drive motor. The main objection to this arrangement appears to be special mechanical features required for its installation. Controls have also been developed that operate on a speed differential between the main drive pulley and an idler pulley. One of these devices is mechanical and is designed to stop the drive motor when the differential in speed between the drive pulley and the idler exceeds a predetermined amount. Another speed-differential device is an electrical control utilizing a generator driven by the main drive pulley connected in a balanced circuit with a second generator driven by the idler pulley. Belt slippage causes an unequal output from the generators, resulting in an unbalance in the electrical circuit. This unbalanced condition is utilized to actuate a relay in the drive-motor control circuit.

It may be noteworthy to mention that most safety devices employed to control belt conveyors in the United States are not designed in such a manner that failure of some parts and circuits will be immediately known. Devices and circuits designed in a manner so that failure of these parts will stop operation immediately are described by the British as "failing to safety." This is certainly a desirable feature in any safety device and perhaps warrants more attention in this country.

Effect of Change in Belt-Conveyor Design

Attempts are being made to improve belt-conveyor performance through new concepts of design. Some of these appear to make their use attractive to the coal-mining industry, since they remove some objections which have heretofore prevented acceptance of the conventional design. It is not anticipated that change in design of belt-conveyor structures will immediately effect safety of operation, except where simplicity of the structures will facilitate removal of spilled material and those designs in which the belt is carried throughout without belt tension on drive pulleys. The elimination of belt-drive pulleys by using other means of traction would of course eliminate one common source of fire in connection with belt-conveyor systems.

Additional Safety Precautions for Operation

The proper installation of belt conveyors is of such importance that good engineering is a necessity; however, the demands are not beyond engineering talent usually available at well-managed operations. Experience has shown that good installations pay off in trouble-free and dependable operation. Manufacturers' instructions and assistance are usually sufficient for the average operation; however, where additional help is needed competent engineering consultants are available.

Since many fires involving belt conveyors have been attributed to electric equipment and circuits, it is imperative that proper attention be given to every detail in selecting and installing such equipment. Electric circuits should have adequate carrying capacity and be adequately protected against short circuits and

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mechanical damage. All connections should be made secure to prevent heating, since fires may be started by overheated joints. Proper use of frame-grounding for protection against electric shock and fire hazards that may result from failure of insulation is essential to overall safety. The use of unbonded sections of conveyor structures as a frame-grounding circuit is discouraged as a result of unfavorable experience in the past. Loosely bolted sections, which are frequently corroded and dirty, form high resistance joints that are unsuited for grounding circuits. Separate grounding circuits for conveyor equipment are advocated.

Elimination of all possible unnecessary combustible material in the vicinity of conveyors, particularly in the area of the drive, is considered a good safety practice. Regular and frequent removal of spillage and prevention of grease and dust accumulations are necessary as a precaution against fires.

Experience has shown that adequate fire-fighting facilities are necessary to prevent property loss when fires do occur. A number of recent fires that were potentially hazardous were brought under control through an adequate supply of water when other fire-fighting facilities had failed. Ventilation of mine entries in which belt conveyors are installed has been given special attention in some States. The requirements are based on the theory of permitting isolation of fires in belt entries from areas that might endanger workmen.

Falls of roof on belt conveyors are a hazard of much concern. Adequate roof support in conveyor entries, plus the use of suitable controls that will stop the drive motor in event of falls of roof, will provide a high degree of protection against fires.

Perhaps one of the most important factors in connection with successful belt-conveyor operation is a good maintenance program. Good maintenance is necessary from the standpoint of safety as well as continuity of operation.

A schedule for testing fire-resistant belts for conveyors has been developed recently by the Bureau of Mines. Belts constructed to meet requirements of this schedule are expected to reduce substantially the fire hazard from excessive belt slip on drive pulleys. It should be recognized that fires may be started by friction even though fire-resistant belts are used where conveyor installations are not properly maintained as regards extraneous combustible materials. As a precaution against this hazard, the Bureau considers it good practice to provide properly adjusted slippage controls with fire-resistant belts.

SUMMARY

The popularity of belt conveyors for transportation in coal mines has increased during the period of mechanization. Because the flexibility of alternating-current power facilities can be utilized for driving conveyors, the Bureau of Mines expects that this form of transportation will be incorporated in many new mines in which all the electrical power for major operations may be alternating current. Changes in design of belt-conveyor structures are being introduced, which may remove some objections raised with conventional structures.

Transportation by belt conveyors within the gradient limitations is usually quite satisfactory where:

1. Proper equipment is selected for the service intended.
2. Installations are made in accordance with good engineering practices.
3. Safeguards against possible hazards of operation (fire-resistant belts and suitable controls) are provided.
4. Good maintenance is practiced throughout.

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